The African Review of Physics (2018) **13**: 0012

Proceedings of the first African Conference on Fundamental Physics and Applications 2018, Namibia. Guest Editors: K. A. Assamagan, M. Backes, D. Charlton, S. Muanza , D. Sahu, and D. Singh

Excess lifetime cancer risk due to natural radioactivity in soils: Case of Karibib town in Namibia

Zivuku Munyaradzi[1,4], Kgabi Nnenesi Anna[2,3], Tshivhase Victor Makondelele[4]

[1]*Department of Natural and Applied Sciences, Faculty of Health and Applied Sciences, Namibia University of Science and Technology, Private Bag 13388, Windhoek, 9000, Namibia. E-mail: mzivuku@nust.na*
[2]*Department of Civil and Environmental Engineering, Faculty of Engineering, Namibia University of Science and Technology, Private Bag 13388, Windhoek, 9000, Namibia.*
[3]*Centre for Environmental Management, University of the Free State, PO Box 339, Bloemfontein, 9300, South Africa.*
[4]*Centre for Applied Radiation Science and Technology, North-West University, Mafikeng Campus, Private Bag X 2046, Mmabatho, 2745, South Africa.*

The Erongo region of Namibia has been reported to experience high natural background radiation resulting from the presence of uranium bearing ores. In order to estimate the radiation risk to the general populace living in the Erongo region, a total of thirty surface soils samples were collected and twenty radon gas monitors (CR-39) were deployed for indoor radon measurements from the gold-mining town of Karibib. The radon gas monitors were deployed in selected households for three months. Naturally occurring radionuclides ^{238}U, ^{232}Th and ^{40}K present in these soils were measured using HPGe γ-ray spectrometer to evaluate the radiation health hazard indices and excess lifetime cancer risk (ECLR). The average activity concentration in Bq/kg for ^{238}U, ^{232}Th and ^{40}K from the soil samples were found to be 58.35±0.10, 62.06±0.06, 952.00± 0.16 respectively. The mean absorbed dose rate in the air (D) was calculated and found to be 104.15 nG/y and the annual effective dose equivalent (AEDE) ranged from 0.06 mSv/y to 0.21 mSv/y with an average of 0.13 mSv/y. The mean concentration of indoor radon gas in the selected households was found to be 79.30±6.68 Bq/m^3 and its annual effective dose was found to be 2.28x10^{-3} mSv/yr. The calculated radiological parameters of some these activity concentrations in the town were higher than the safe limits which may present a serious public health problem because the soil is used as building construction material for the local community. The mean excess lifetime cancer risk (ELCR) due to radionuclides in soil was found to be 0.44x10^{-3}, which slightly higher than the world average value of 0.29 x10^{-3}.

1. Introduction

The environmental radioactivity and the associated external exposure due to gamma emitting radionuclides depend on the underlying rocks and consequently the soil type and the geographic conditions which varies both in spatial and temporal [1]. The most important radionuclides of radiological concern are from uranium-238 (^{238}U) series, thorium-232 (^{232}Th) series and the non-series potassium-40 (^{40}K).

The commissioning and coming into production of the Navachab Gold Mine in the Karibib District in 1989 was a result of the more recent upswing in gold exploration [2]. During the process of mineral mining and milling large quantities of wastes which contains radionuclides and toxic chemicals are generated and these are discharged into the environment where they may contaminate the soil, negatively impacting the environment and human health [3] and may affect the nearby communities [4].

Long term exposures to radioactivity and inhalation of radionuclides have serious health effects such as chronic cancer, [5]. Similarly, exposure to radon and short-lived alpha progeny solid particles can lead to lung cancer as these particles interact with the alveola lining where they leave tracks of ionizing radiation in the structure of DNA [2].

It is critical to evaluate soil radioactivity to understand background radiation concentrations. Measurements of terrestrial gamma dose rates is also essential since gamma radiation provides information concerning excess lifetime cancer. However, in Namibia, there are few studies which have been carried out to evaluate soil radioactivity [7,8,9] and terrestrial dose rates but limited in estimating lifetime cancer risk especially in mining environment. Thus, the aim of this study is to evaluate soil radionuclides radioactivity as well as indoor radon dose rates in the town of Karibib a dormitory town nearby Navachab Gold mine of Erongo region, Namibia.

2. Materials and Methods

2.1 Study Area

Karibib is a satellite town for Navachab Gold mine in the Erongo region of Western Namibia and

it is highly affected by mining activities from the mine operations. The town is located 10 km North of Navachab Gold Mine and has a population of 3, 800 inhabitants and the area cover 97 square of town land. The town is situated on the Khan River, halfway between the capital city, Windhoek and the coastal town of Swakopmund. The town is known for its aragonite marble quarries and gold mining activities. Figure 1 shows the layout of Karibib town.

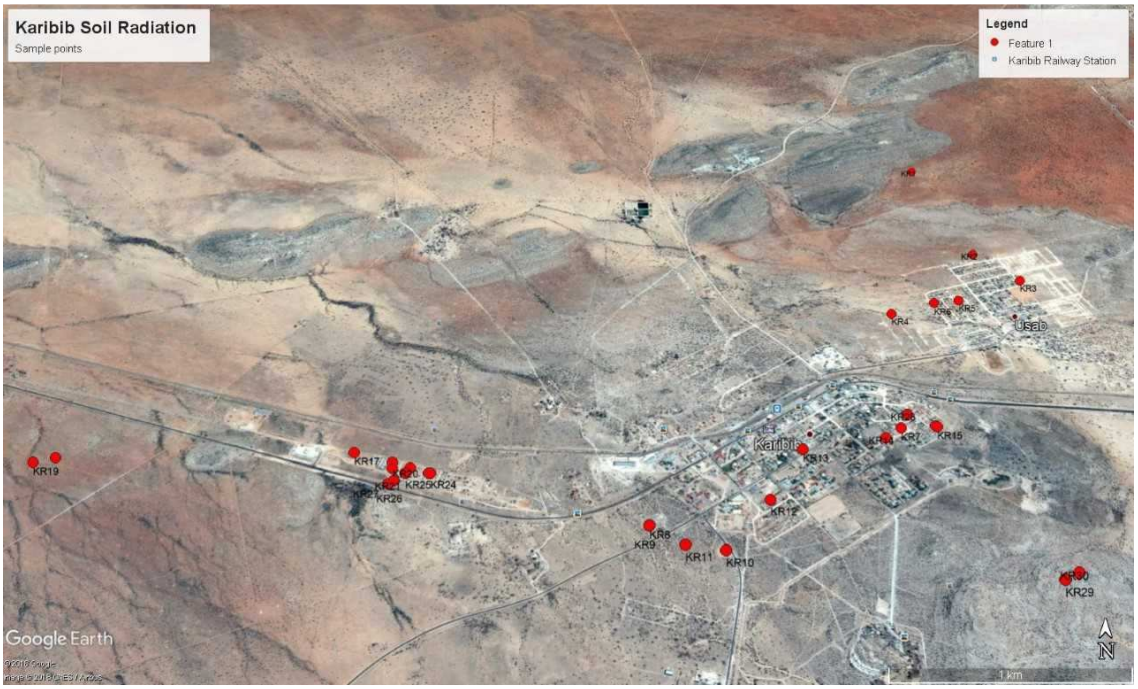

Figure 1.0 The map of Karibib town showing some sampling sites, i.e., collection of soil samples and deployment of Radon gas monitors.

2.2 Sample collection and preparation:

2.2.1 Soil Samples

Thirty soil samples were randomly collected from five residential locations of the town of Karibib. The sampling sites include open space such as playground, areas along the road and the areas within the residential areas. For each sampling site, an area of about 1 m^2 was marked with the Geographical positioning system (GPS) and carefully cleared of debris to a few centimetres depth. Surface soils of 0.5 kg were extracted using a soil auger to a depth of about 0.5 m and placed in plastic bags. The soil samples were mixed together thoroughly, to obtain a representative sample of the area. Each soil sample was labelled according to the geographical coordinates of the sampling area, and the coordinates were later used to indicate the position on the simplified map by an open circle point. All the samples were transported to the Namibia University of Science and Technology (NUST) Physics laboratory for processing. The samples were kept at 100 ^{0}C in an oven for drying, and to allow the outflow of moisture. The samples were transferred into 500 ml Marinelli beakers and firmly sealed and stored for four weeks to ensure a state of equilibrium between radium isotopes and their respective daughters [10].

2.2.2 Radon

Measurements of radon were performed in residential homes by using Radon Passive alpha C-39 detectors. The dosimeters were installed at a distance of 2 metres above the ground and exposed to ambient air in each sitting room of the selected residential houses. The measurements were done over a period of three months (May to August) to improve reliability. Precaution was taken not to install the dosimeters directly to the source of sunlight or closer to windows and other electronic gadgets that that can disturb the flow of currents. After 90 days the C-39 dosimeters were retrieved and etched at a Parc Radon Gas Monitors (ParcRGM) Pty laboratory in South Africa.

2.3 Activity Concentration Measurements

The activity of the samples was counted using a HPGe detector on a high-resolution gamma spectrometry system at NUST Physics laboratory. The detector was co-axial n-type high purity germanium detector which has a resolution of 2.0keV at 1332keV of ^{60}Co with a relative efficiency of 46 %. The output of the detector was analysed using Canberra Genie 2000 software (Genie ™ 2000). The energy and efficiency calibrations of the gamma spectrometer were performed using IAEA composite standards of Cadmium-109, Strontium-85 and Cobalt-60 before sample measurements. The detector was lead shielded to avoid background radiation and the Marinela beakers were placed directly on top of the detector to measure the gamma photons. The background radiation was carefully subtracted from each sample after being measured using and an empty Marinela beaker under similar conditions in which the samples were run. The samples were counted for a period of 12 hours and the spectra were analysed for ^{238}U (^{226}Ra), ^{232}Th and ^{40}K.

The activity concentrations of each radionuclide were determined by considering the average activities of the daughters in each series at the given photo peak except where there was interference. i.e. ^{238}U was determined using photo-peak 609keV (46.1%) and 1120.3keV (15.7%) from ^{214}Bi and 295.2keV (19.7%) and 351.9 (38.9%) from ^{214}Pb. ^{232}Th activity was determined from the gamma-rays of 238.6keV (44.6 %) from ^{212}Pb and 338.3keV (11.4 %), 911.6keV (27.7%) and 969.1keV (16.6 %) from ^{228}Ac while ^{40}K concentration was determined from its gamma energy line at 1406.2keV (10.7 %). The activity concentrations of radium, thorium and potassium in Bq kg^{-1} of the radionuclides in the composite soil samples were calculated using equation (1) [12].

$$A_{Bq.kg^{-1}} = \frac{C_{NP}}{B.I \times \varepsilon(E_\gamma) \times m} \quad (1)$$

where C_{NP}= net peak counts for a given energy line, $B.I$ = branching intensity, $\varepsilon(E_\gamma)$ = the absolute photo-peak efficiency of the detector and m is the mass of the sample in kg.

2.4 Dose Calculations

2.4.1 Absorbed dose (D)

The mean activity concentrations of ^{238}U, ^{232}Th and ^{40}K are converted into dose rate by applying factors 0.462, 0.604 and 0.0417 for radium, thorium and potassium respectively [11] as illustrated in equation (2).

$$D = (0.462C_U + 0.604C_{Th} + 0.0417C_K)\ \text{nGyh} \quad (2)$$

where D is the absorbed dose rate in the outdoor air at 1.0 m above the ground (nGyh^{-1}), C_U, C_{Th} and C_K are the activity concentrations (Bq.kg^{-1} of ^{238}U, ^{232}Th and ^{40}K) in soil samples respectively. Since absorbed dose only represents dose in the air, the dose received by the adult members of the public is taken into consideration and another term known as the annual effective dose equivalent is introduced.

2.4.2 The Annual effective dose Equivalent (AEDE)

The annual effective dose equivalent (AEDE) received by a member of the public is calculated from the absorbed dose rate by applying dose conversion factor of 0.7 Sv.Gy^{1} and the outdoor occupancy factor 0.2 [13] and this illustrated by equation (3).

$$AEDE\ (mSv/yr) = D_R \times DCF \times F_2 \times T \quad (3)$$

where F_2 denotes the external outdoor occupancy factor 0.2, DCF is the dose conversion factor of 0.7 Sv.Gy^{-1} and T is the time = 8760 hours per year.

2.5 Radiation Indices measurements

The measured activity concentrations of ^{238}U (^{226}Ra), ^{232}Th and ^{40}K were used to calculate radiation parameters and these are radium equivalent, indoor doses, annual effective dose and excess lifetime cancer risk.

2.5.1 Radium equivalent (Ra_{eq})

Radium equivalent (Ra_{eq}) activity is used to assess the radiation hazards associated with materials containing ^{226}Ra, ^{232}Th and ^{40}K in Bq.kg^{-1} [14]. It is well documented that these radionuclides emit gamma doses in differing amount of activities even when they are of the same amount in any material. The radium equivalent (Ra_{eq}) is calculated on the assumption that 370 Bq kg^{-1} of ^{226}Ra or 259 Bq kg^{-1} of ^{232}Th or 4810 Bq kg^{-1} of ^{40}K produce the same gamma dose rate [15]. The Ra_{eq} of the sample in Bq kg^{-1} was achieved using equation (4) [16].

$$Ra_{eq} = \left(\frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810}\right) \times 370 \quad (4)$$

where A_{Ra}, A_{Th} and A_K = Activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K respectively. The Radium equivalent is the most important reference standard for regulating safety standard on radiation protection for the public [14].

2.5.2 Hazard indices (H_{ex} and H_{in})

When radioactive materials decay, they produce either external radiation or internal radiation which results in the exposure of human being. The two indices that represent external and internal radiation hazards, are represented mathematically by equations (5) and (6) [17].

$$H_{ex} = \frac{A_U}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \leq 1 \quad (5)$$

$$H_{in} = \frac{A_U}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \leq 1 \quad (6)$$

where A_U, A_{Th} and A_K are the radioactivity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in Bqkg^{-1} of soil samples respectively. The value of this index must be less than a unity for the radiation hazard to be negligible and this value corresponds to upper limit of Ra_{eq} of 370 Bq.kg^{-1} [19].

2.5.3. Excess Lifetime Risk (ELCR)

This represent the chance of developing cancer over a lifetime at any given exposure level due radiation. It is presented as a value representing the number of extra cancers expected in a population exposed to a carcinogen at a given dose, and this can be calculated by considering the life expectancy of a human being to be 70 years [17] and is shown by equation (7).

$$ELCR = AEDE \times DL \times RF \quad (7)$$

where AEDE = the annual effective Dose Equivalent, DL = the average duration of human life (estimated to be 70 years) and RF = the risk factor (Sv^{-1}), fatal cancer risk per sievert. For stochastic effects, which produce low background radiation, the ICRP 60 stipulates a value of 0.05 for the public exposure [17].

2.6 Radon measurements

The concentrations of indoor radon recorded with CR-39 (C_{Rn}) in Bq.m^{-3} can be expressed in terms of equilibrium equivalent radon concentration (EEC_{Rn}) by the relation given in equation (8) and that of equivalent dose received by the bronchial and pulmonary tissues in human lungs by using the dose conversion factor (DCF) of 1.0 x 10^{-5}mSv per Bqh.m^{-3} [4] and equilibrium factor (F) of 0.45 as stipulated in equation (9).

$$EEC_{Rn} = F \times C_{Rn} \quad (8)$$

Equivalent dose = $EEC_{Rn} \times$ DCF (9)

2.6.2 The effective indoor dose rate due to radon and its progeny (H_E)

To calculate the annual effective dose from exposure to radon, the conversion factor of 9.0 nSv/h per Bq/m^3 [21] and an indoor occupancy factor of 0.8 [22] and equilibrium factor of ^{22}Rn of 0.4 was use used according to equation (10).

$$H_E = c_{Rn} \times F \times T \times DCF \quad (10)$$

where H_E = effective indoor dose rate in mSv/yr, C_{Rn} = the arithmetic mean radon concentrations in Bq/m^3, F = 0.4 the recommended equilibrium factor value used for indoor radon, T = indoor occupancy time of 7000 h and DCF = recommended value 9.0nSv (Bqm^{-3}h)$^{-1}$ or 9nSv/Bqhm^{-3} or 9.0x10^{-6} mSv/h per Bq/m^3 to convert radon equilibrium-equivalent concentration to population effective dose [22].

2.6.3 Inhalation dose Calculations

The total inhalation effective dose (TID_{Rn}) from radon has been calculated by using the conversion of radon concentration (C_{Rn}) and its Equilibrium-Equivalent radon concentration (EEC_{Rn}); of 0.17, 9nSvBq^{-1}h^{-1}m^3 respectively as recommended by United Nations Scientific Committee on the Effect of Atomic Radiation as illustrated in equation (11) [23,24].

$$TID_{Rn}(mSv/y) = [(C_{Rn} \times 0.17) + (EEC_{Rn} \times 9)] + (8760 \times 0.8 \times 10^{-6}) \quad (11)$$

3. Results and Discussions

3.1 Activity concentration and radiological parameters

Table 1.0 shows the results for activity concentrations and radiological parameters due to ^{238}U, ^{232}Th and ^{40}K in the soil samples collected from Karibib town. The activity concentrations vary from 29.26$\pm$0.02 Bq.kg^{-1} to 100.72$\pm$0.02 Bq.kg^{-1}, 31.94 $\pm$0.02 Bq.kg^{-1} to 101.48$\pm$0.06 Bq.kg^{-1} and 215 .00 $\pm$0.14 Bq.kg^{-1} to 1400.00 $\pm$0.18 Bq.kg^{-1} with an average of 58.35$\pm$0.10 Bq.kg^{-1}, 62.06$\pm$0.06 Bq kg^{-1} and 952.13 $\pm$0.16 Bq.kg^{-1} for ^{238}U, ^{232}Th and ^{40}K respectively. It can be observed that sample K22 and K28 have a higher activity concentration of 101.48$\pm$0.06 Bq.kg^{-1} and 100.72$\pm$0.02 Bq.kg^{-1} for ^{232}Th and ^{238}U respectively. This can be attributed to the fact that these sites are within the granite milling plant. Granite rock is known to have high concentrations of uranium and thorium. The soil samples have a higher concentration of potassium-40 with an average value of 952.13 $\pm$0.16 Bq.kg^{-1}

and this is due to geological underlying rocks which are mainly composed of metasedimentary and meta-volcanic rocks with meta-morphed equivalent of fluviates quartzites, lime-stones, marls, turbidites and shales [25,26]. In general, the soil samples collected have an equal proportions of activity concentrations for ^{238}U and ^{232}Th and a higher concentration of ^{40}K

Table 1.0 Activity concentration and radiological parameters (Absorbed dose (D), Annual Effective dose Equivalent (AEDE), Radium equivalent (Ra_{eq}), External hazard index (H_{ex}), Internal Hazard Index (H_{in}) and Excess Lifetime Cancer Risk (ELCR) in soils samples collected from town of Karibib.

Sample ID	Activity concentration (Bq. kg^{-1}) ^{238}U	^{232}Th	^{40}K	D (nGy^{-1})	AEDE (mSvy^{-1})	Ra_{eq}	H_{ex}	H_{in}	ELCR (10^{-3})
K1	54.94±0.04	61.42±0.04	1260±0.17	115.02	0.14	239.61	0.65	0.80	0.49
K2	66.82±0.06	89.72±0.06	887±0.12	122.05	0.15	263.22	0.71	0.89	0.52
K3	58.02±0.04	51.76±0.03	900±0.12	95.60	0.12	201.19	0.54	0.70	0.41
K4	43.55±0.06	34.59±0.08	226±0.15	50.44	0.06	110.35	0.30	0.42	0.22
K5	78.62±0.07	80.06±0.05	1310±0.17	139.31	0.17	293.76	0.79	1.01	0.59
K6	40.90±0.03	45.16±0.03	1280±0.17	99.55	0.12	203.88	0.55	0.66	0.42
K7	60.58±0.05	75.86±0.05	1210±0.16	124.26	0.15	262.03	0.71	0.87	0.53
K8	49.32±0.04	31.94±0.02	395±0.05	58.55	0.07	125.33	0.34	0.47	0.52
K9	63.46±0.05	64.80±0.04	1330±0.17	123.92	0.15	258.34	0.70	0.87	0.53
K10	50.88±0.04	56.58±0.04	1260±0.17	110.22	0.14	228.63	0.62	0.76	0.47
K11	67.52±0.05	70.20±0.04	1320±0.17	128.64	0.16	269.34	0.73	0.91	0.55
K12	53.63±0.96	56.68±0.60	215±0.14	68.10	0.08	151.43	0.41	0.55	0.29
K13	85.12±0.16	95.30±0.15	1258±0.89	149.37	0.18	318.09	0.86	1.09	0.64
K14	55.82±0.04	45.06±0.02	1400±0.18	111.39	0.14	227.88	0.62	0.77	0.47
K15	55.76±0.05	79.40±0.05	881±0.12	110.46	0.14	236.96	0.64	0.79	0.47
K16	57.20±0.05	77.66±0.05	957±0.17	113.24	0.14	241.76	0.65	0.81	0.48
K17	29.26±0.02	14.93±0.04	245±0.03	32.75	0.04	69.43	0.19	0.27	0.14
K18	70.48±0.05	39.62±0.03	484±0.06	76.68	0.09	164.31	0.44	0.63	0.32
K19	56.86±0.05	71.56±0.05	901±0.12	107.06	0.13	228.40	0.62	0.77	0.46
K20	36.54±0.03	33.38±0.02	1040±0.14	80.41	0.10	164.23	0.44	0.54	0.34
K21	46.72±0.04	84.28±0.05	937±0.17	115.56	0.14	239.20	0.65	0.77	0.47
K22	75.08±0.07	101.48±0.06	837±0.11	130.88	0.16	284.44	0.77	0.97	0.56
K23	38.86±0.03	36.32±0.02	685±0.09	68.46	0.08	143.44	0.39	0.49	0.29
K24	45.10±0.04	42.24±0.03	1080±0.14	91.39	0.11	188.52	0.51	0.63	0.39
K25	90.80±0.07	73.86±0.05	804±0.11	120.09	0.15	258.16	0.70	0.94	0.51
K26	49.94±0.04	58.22±0.04	1060±0.14	102.44	0.13	214.65	0.58	0.72	0.44
K27	60.90±0.05	49.80±0.02	931±0.12	96.60	0.12	202.63	0.55	0.71	0.41
K28	100.72±0.02	99.12±0.06	1490±0.20	168.53	0.21	356.94	0.96	1.24	0.72
K29	59.76±0.05	61.56±0.04	1060±0.14	108.99	0.13	229.24	0.62	0.78	0.46
K30	47.36±0.04	79.90±0.04	921±0.17	108.55	0.13	232.35	0.63	0.76	0.46
Max	100.72±0.02	101.48±0.06	1400±0.18	168.53	0.21	356.94	0.96	1.24	0.72
Min	29.26±0.02	31.94±0.02	215±0.14	32.75	0.06	69.43	0.19	0.27	0.14
Mean	58.35±0.10	62.06±0.06	952±0.16	104.15	0.13	220.26	0.60	0.75	0.44

The outdoor terrestrial gamma dose rates were higher compared to the permissible limits receipted by United Nations Scientific Committee on the Effect of Atomic Radiation. (UNSCEAR) [11, 14] in most of the soil samples with an average of 168.53 nGy/h. This value is 3.0 times higher than the world average value of 51.00 nGyh^{-1} [11]. The present mean value of annual effective dose equivalent (AEDE) is 0.13mSv/y which is lower than 1.0mSv/y recommended for the members of the public by ICRP and this value is lower than the average world value of 0.48mSv/y [4]. This means that the AEDE

average values from the soil samples collected from the town of Karibib is within the safe limits for the general populace. The calculated values of hazard indices for soil samples ranged from 0.19 to 0.96 with an average of 0.60 and from 0.21 to 1.24 with an average of 0.75 for the external hazard (H_{ex}) and internal hazard (H_{in}) respectively. The average values of radiological hazards determined in this study are less than unity. This does not constitute a health hazard to the inhabitants of Karibib town. The excess lifetime cancer risk (ELCR) ranges from 0.14 x 10^{-3} in sample K17 to 0.72 x 10^{-3} in sample K28 with an average of 0.44 x 10^{-3} as shown in Table 1.0. This average value of ECLR is 1.5 times higher than the world average of 0.29 x 10^{-3} [17]. This implies that the chances of having cancer by the general populace is higher due to activity of the radionuclides

3.2 Indoor Radon

The results for indoor radon concentrations (C_{Rn}), Equilibrium-Equivalent dose (EEC_{RN}), Equivalent Dose (D_{RN}), Effective indoor dose rate (H_E) and total inhalation dose (TID_{RN}) due to radon are presented in Table 2.0. Indoor Radon concentrations and its progeny in the selected residential homes range from 70.80$\pm$6.48 Bq/m^{3}to 86.30$\pm$6.44 Bq/m^3 with an average of 79.30 Bq/m^3 which is slightly higher than the indoor radon level emanation but lies within the reference level of 300Bq/m^3 [27]. Higher concentrations of indoor radon and its progeny can be attributed to thoron rich building materials derived mainly of granitic and felsite rocks which are used as a raw material for the construction of these dwellings. The concentration of radon and its progeny is influenced by seasonal variation and location where the measurements are made, the geology of the rock and hence the soils, the permeability of radon from the ground, ventilation of the dwelling, the size and age of the dwelling. The indoor radon effective dose rate varies from 2.04 x 10^{-3} to 2.49 x10^{-3}mSv/y and the average were found to be 2.28 x10^{-3}mSv/y which are significantly lower than the safe limits [11].

Table 2.0: The indoor radon concentrations (C_{Rn}) and associated doses received due to radon and its short-lived progeny exposure.

Sample ID	Conc. Radon (C_{Rn}) (Bq/m^3)	EEC_{RN}	Equivalent Dose	H_E (mSv/y)	TID_{RN}
RK1	81.30$\pm$6.62	36.56	3.66E-03	2.34E-03	2.40
RK2	81.81$\pm$6.62	36.65	3.97E-03	2.54E-03	2.61
RK3	74.00$\pm$6.71	33.29	3.33E-03	2.13E-03	2.19
RK4	85.80$\pm$6.80	38.63	3.86E-03	2.47E-03	2.54
RK5	83.60$\pm$7.26	37.60	3.76E-03	2.41E-03	2.47
RK6	84.50$\pm$6.85	38.01	3.80E-03	2.43E-03	2.50
RK7	73.10$\pm$6.30	32.88	3.29E-03	2.10E-03	2.16
RK8	73.50$\pm$6.76	33.08	3.31E-03	2.12E-03	2.17
RK9	80.80$\pm$6.89	36.37	3.64E-03	2.33E-03	2.39
RK10	70.80$\pm$6.48	31.85	3.18E-03	2.04E-03	2.09
RK11	82.60$\pm$6.58	37.19	3.72E-03	2.38E-03	2.44
RK12	76.70$\pm$7.21	34.52	3.45E-03	2.21E-03	2.27
RK13	84.90$\pm$6.39	38.22	3.82E-03	2.45E-03	2.27
RK14	74.00$\pm$6.80	33.29	3.33E-03	2.13E-03	2.51
RK15	72.10$\pm$6.89	32.47	3.25E-03	2.08E-03	2.19
RK16	80.80$\pm$6.94	36.37	3.64E-03	2.33E-03	2.13
RK17	85.40$\pm$6.40	38.42	3.84E-03	2.46E-03	2.39
RK18	73.50$\pm$6.48	33.08	3.31E-03	2.12E-03	2.53
RK19	74.40$\pm$6.16	33.49	3.35E-03	2.14E-03	2.17
RK20	86.30$\pm$6.44	38.84	3.88E-03	2.49E-03	2.20
Min	70.80$\pm$6.48	31.85	3.18E-03	2.04E-03	2.09
Max	86.30$\pm$6.44	38.84	3.88E-03	2.49E-03	2.54
Mean	79.30$\pm$6.68	35.69	3.57E-03	2.28E-03	2.35

4. Conclusion

The natural radioactivity levels of ^{238}U, ^{232}Th and ^{40}K have been measured in 30 samples using HPGe detector attached to gamma spectrometer. The results in this study are in agreement with previous studies in the same locale and some parts of Africa and the world, which are 11 to 64 for ^{238}U, 17 to 60 for ^{232}Th and 140 to 850Bq kg^{-1} for ^{40}K [13]. The samples satisfy the universal standards of limiting the radioactivity to within safe limits of 1000, 1000 and 4000Bq kg^{-1} for ^{238}U, ^{232}Th and ^{40}K respectively [28]. The average radiological parameters i.e. radium equivalent, radiation indices and lifetime cancer risk were significantly higher than the world average values. On the other hand, the annual effective dose is lower than 1.0mSv/y the recommended safe limit for members of the public [13]. The indoor radon concentrations and its progeny are within the recommended action levels of 300Bq/m^3 for residential places [27]. The indoor effective annual dose and total annual inhalation dose due to radon and its progeny are within the safe limit as recommended by [11].

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Received: 11 October, 2018

Accepted: 20 October, 2018